Reducing non-contact electric arc injuries: An investigation of behavioral and organizational issues

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Abstract

Problem: It is estimated that 5 to 10 arc flash explosions occur in electric equipment every day in the United States. In the mining industry the largest single injury category of electrical injuries are caused by non-contact electrical arcs. *Method:* This investigation progressed in two phases: (a) 836 Mine Safety and Health Administration (MSHA) reports of electric arcing incidents that occurred over a period of 11 years were reviewed, and (b) personal interviews were conducted with 32 individuals. A theoretical Safe Job Performance Model guided the study. *Results:* Behavioral dimensions were identified and included the effect of worker experience, judgment and decision-making ability, behavioral and organizational controls, and safety culture. *Summary:* The National Institute for Occupational Safety and Health (NIOSH) conducted an investigation of behavioral components associated with arc flash incidents and developed recommendations for interventions based on findings. *Impact on Industry:* This study fills a vacuum in electrical training with a focus on the organizational and behavioral aspects of arc flash incidents. The research is cross-cutting in its scope, in that the results apply not only to mining and construction, but many other industries employing electricians. Although the majority of mine electrical injuries are the results of burns from electrical arcs, few miners are aware that such a hazard exists. A safety training program, which includes a video and an instructor's discussion guide, was developed for electricians based on this study's findings. "Arc Flash Awareness" was released in 2007 (DHHS NIOSH Publication No.2007-116D) and is available through 1-800 CDC INFO. Phone: 1-800 232-4636 or email cdcinfo@cdc.gov. It is also available from MSHA at MSHADistribution@dol.gov or 304-256-3257 (DVD-576). Private industry is producing Portuguese and Spanish language translations.

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1. Introduction

An electric arc results from the release of electrical energy through the air when high voltage exists across a gap between conductors. Staged tests using mannequins at the Paul Gubany High Power Laboratory in 1996 repeatedly demonstrated that electrical arcs are highly unpredictable and variable in occurrence, energy, path, and duration (Jones et al., 2000).

Arc faults give off thermal radiation and bright, intense light that can cause burns to the body, especially to the skin and eyes. Next to the laser, the electric arc is the hottest event on earth, with recorded temperatures as high as 35,000° F (McCabe, 2005). High-voltage arcs can also produce a considerable pressure wave by rapidly heating the air and producing a blast that may exceed 200 lbs/sq ft (978 kg/sq m). This pressure burst can send molten metal droplets from melted copper and aluminum components in electrical equipment great distances at extremely high velocities. In addition to direct personal injury from these hot metals, arc blasts can throw a worker against nearby objects or walls, causing secondary injuries such as blunt force trauma, cuts, and abrasions. The impulse sound wave near the unprotected ear can also result in temporary or permanent traumatic hearing loss.

"Non-contact" arc flash burns refer to electrical burn injuries without accompanying electric shock. The person receiving the arc burn never actually contacts an energized electrical conductor. The burn occurs, therefore, when the worker is exposed to sufficient electromagnetic radiation from an electric arc. The radiation covers a wide band of the electromagnetic spectrum, from the infrared and visible range to well beyond the ultraviolet. The burn can range from a mild reddening of the skin (1st degree) to complete destruction of skin, underlying muscle, and connective tissue (3rd degree) (Capelli-Schellpfeffer, 2004).

The hazards of a non-contact electric arc flash are present at most industrial workplaces. CapSchell, Inc. estimates that 5 to 10 arc flash explosions occur in electric equipment every day in the United States (Fischer, 2004). In the mining industry, during one recent 12 year period, 36,373 lost work days were recorded for all electrical injuries. The largest single injury category within this total was non-contact electrical arc injury. These incidents resulted in three fatalities, more than 12,000 lost work days (one-third of the total), and an average of 21 lost work days per incident (Kowalski-Trakofler et al., 2003).

Personal accounts from electricians also note that many workers have experienced some degree of exposure to an electric arc flash during the conduct of their work. However, because these occurrences did not result in an injury, they were not reported. Explanations for escaping injury have ranged from "pure chance" to practicing proper work procedures, such as using personal protective equipment (PPE).

The population of workers who may be affected by electric arc flashes could be on the rise. In 2002, the U.S. Department of Labor reported there were 659,000 electricians on the job. Projected growth of the number of jobs available by 2012 is an estimated 814,000 electricians on the job. This is higher than other similar technical professions.

With this increase in electrical workers and the fact that non-contact arcing incidents can result from human error as well as from equipment malfunctions, it may be inferred that accidents related to human behavior could also be on the rise.

Non-contact arcing incidents can be spontaneous, such as in the following example:

> *An electrical foreman and an electrician had just replaced a 480-volt circuit breaker panel with a 1000-volt circuit breaker panel. Following this, the 7200-volt transformer power was re-energized; however, the circuit breaker could not be energized. The electrician began to look at the ground check relay as the source of the problem when an electric arc occurred. After the smoke cleared, it was observed that the 1000-volt circuit breaker panel was leaning outward as it had been left unbolted by the foreman and the energized line side 995-volt connections had contacted the transformer frame. This produced an electrical arc that resulted in serious burns to both hands and face of the electrical foreman.*

In addition, non-contact arcing incidents can result from a worker inadvertently bridging electrical contacts with a conducting object. Other causes of arc flash hazards may include actions such as dropped tools and the build up of conductive dust and corrosion. Arcing faults can also occur with direct current, such as mine DC trolley systems or batteries (Hall, Myers, & Vilcheck, 1980).

Standards for protecting workers against the hazards of an arc flash are included in NEC 2002 (National Electric Code); IEEE Standard 1584 (Institute of Electrical & Electronic Engineers); OSHA 29 CFR 1910 (Occupational Safety and Health Administration); and NFPA 70E (National Fire Protection Association). NEC 110.16 requires arc flash warning labels to raise the level of awareness of electrical arc flash hazards. IEEE Standard 1584 addresses arc flash calculations for arcing faults, incident energy, and flash boundary. OSHA requires that "live" parts greater than 50 volts to ground be deenergized unless the employer can demonstrate that deenergizing introduces additional hazards or is infeasible. In the 1970's, OSHA requested the NFPA to develop a standard for electrical safety for workers. The latest edition of NFPA 70E was completed in 2004. It is the most widely applied electrical safety standard for employee workplaces today. Most notably, it is the first standard to specifically include arc flash PPE in work practice requirements, as it contains the most protective PPE requirements in the world. Among its many safety practices, it proposes training for all workers exposed to potential arc flash or electrical shock hazards. This includes both task-qualified workers as well as electrically unqualified workers.

OSHA enforces NFPA 70E under the "General Duty Clause" in the 29 CFR 1910 (Code of Federal Regulations), which requires employers to furnish a workplace that is free from recognized hazards that may cause death or serious physical harm. According to this mandate, training is required for unqualified as well as qualified employees. This training is left to the employer to administer and can be given on the job or in the classroom. In effect, all employees who face the risk of electrical injury are required to be trained. The strategy found in NFPA 70E includes training for all workers exposed to potential arc flash hazards. This includes operators who may be "task qualified" to operate a disconnect, electrically unqualified workers, and office personnel. All are required to be trained in the basics of electrical safety to prevent unqualified persons from entering live work and arc flash zones (Hoagland, Shinn, & Reed, 2004a,b).

Commercially available electrical training programs generally focus on technical skills, instrumentation, safe operating procedures, and personal protective equipment. Protective equipment, including clothing, is one way of preventing arc flash injury. In recent years, much effort has been applied to various types of flame-resistant clothing and to determining weights and construction of natural fibers that resist ignition. In short, the level of protection must match the category of the hazard and, in addition to thermal protection, the PPE system must also be comfortable and durable (Laverty, 2001). Accepted PPE includes flame-resistant clothing, flash suits (for high-energy arc exposure), flash suit hoods, insulating gloves, and insulated tools. These are in addition to the normally used hard hat, safety shoes, safety glasses, and hearing protection. Face shields, which are generally protective against arc hazards, have also become available for workers. Some negative factors associated with face shields include decreased peripheral vision, increased heat, and worker discomfort. At any energy level, nevertheless, face shields can help protect workers from much of the flying metal particles produced by the arc (Hoagland, 1996).

Protective clothing, though, does not take the place of proper safety training. Michael Enright, an executive with a commercial supplier of flame-resistant clothing stated that, "Safety equipment should be the last line of defense. There are a number of things that can be done on the front end from the initial engineering design of the equipment, to the maintenance of the equipment, to the training of the individual who operates the equipment" (Naso, 2004, p.44). Left out of most training programs, however, is instruction on individual and organizational behavior that attempts to influence workers' and employers' attitudes, beliefs, or behaviors.

There is a growing body of research that indicates job and organizational level factors have a powerful influence on safe behavior and the occurrence of accidents/injuries (DeJoy, Gershon, & Schaffer, 2004). One such factor is safety climate or safety culture, which is defined as the shared perceptions of workers about the level of safety in their workplace. Employee perceptions about safety are important because workplace injuries have been correlated with safety climate, such that organizations with strong safety climates consistently report fewer injuries than organizations with weak safety climates.

There are several key factors associated with a safe workplace. A safe workplace typically features strong management committed to occupational safety programs where safety is integrated into the structure of the organization and there is adequate support for the safety manager. Also, in safe workplaces, safety performance is assessed periodically, and employees receive feedback on their performance. Another important factor associated with a safe workplace is the use of experienced workers to train younger workers in safety procedures and policies along with worker involvement in safety activities, such as worker safety tool talks before shift and joint labor/management safety committees. Safe work environments emphasize housekeeping and workplace cleanliness. In addition, previous studies have shown that younger workers as opposed to older workers have a higher frequency of accidents. However, older workers tend to have more severe accidents and are away from work for longer periods of time as a result (Fotta & Bockosh, 2000).

Given the rising number of incidents, a multi-disciplinary team of NIOSH researchers led an investigation of non-contact arc flash incidents by studying various individual and organizational behavioral aspects of past incidents. This paper identifies many of these behavioral characteristics and proposes training interventions, which, if eventually developed into instructional exercises, could reduce the frequency and severity of arcing incidents.

2. A Model for Safe Job Performance

This study is part of a larger, ongoing NIOSH project in which engineering solutions are being investigated to limit arc flash incidents. To coordinate the overall effort of the project, the authors developed a theoretical Safe Job Performance Model. The model, illustrated in Fig. 1,

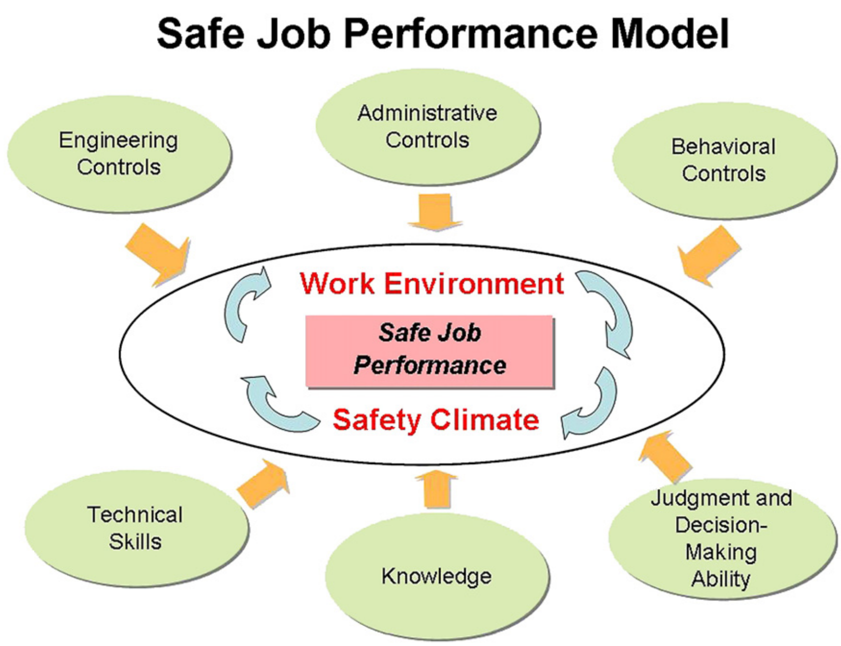

Fig. 1.

combines engineering controls with administrative and behavioral components along with specific skills. The core of the model is the safety climate or the work environment of the company or organization. Making up this core are six components that serve as a foundation to support both the organization and the individual to ensure safe job performance. They include engineering controls, administrative controls, behavior controls, technical skills, knowledge, and judgment and decision-making ability.

Engineering Controls, or interventions, are physical manipulations of the sources of the hazard or the manner of exposure to the hazard. Examples include controlling noise, chemical exposure, heat, erecting barriers, positioning switches for safer use, and redesigning electrical tools and equipment.

Administrative Controls are initiatives by management to modify a work process or exposure. Examples of administrative interventions might be developing a standard operating procedure, and adjusting work practices such as job rotation or better shift schedules. Also, training is sometimes considered an administrative intervention.

Behavioral Controls focus on influencing workers' and employer's attitudes, knowledge, belief, or behaviors concerning work hazards or issues of worker health. Examples include training workers to wear PPE, implementing behavior modification techniques such as feedback to instill safer behavior, and promoting programs to encourage worker health, such as stop-smoking plans.

Technical Skills refer to the hands-on skills and abilities needed to get the job done and complete the electrical task successfully. Technical skills explain "how" a worker does the job.

Knowledge refers to the basic information needed in order to understand the process of the electrical task. Knowledge is an important underpinning of safe job performance. Workers need to understand the task within the context of the overall job, in addition to having the skills to perform the task.

Judgment and Decision-making refers to the workers' ability to make sound and safe decisions. Most electrical training programs today include the important subject areas of "technical skills" and "knowledge." Thus, the addition of administrative and behavioral controls, and judgment and decision-making ability can enhance the effectiveness of these training efforts. This model may have application not only in the development of a training program, but also as a tool to evaluate an electrical safety program. NIOSH reports that program evaluation is a key issue in training. NIOSH researchers note that during the past 40 years, knowledge of the causes of work-related disease and disability has grown dramatically, however, "ways to evaluate occupational health and safety interventions is sparse" (Goldenhar & Schulte, 1996).

3. Method of Study

The investigation was conducted in two phases. Phase One involved a review of 836 MSHA narratives of electric arc incidents that occurred in the mining industry over an 11 year period. Phase Two followed with 32 personal interviews with *victims of* or *witnesses to* a non-contact electric arc event.

3.1. Phase One

3.1.1. Subjects

The subjects were 836 individuals who experienced an arc flash incident between 1990 and 2001, as reported to the U.S. Mine Safety and Health Administration (MSHA). The Code of Federal Regulations 30 Part 50 mandates mine operators and independent contractors, whose employees perform certain types of work on mine property, to file a *Mine Accident, Injury and Illness Report* for reportable incidents within 10 working days after the incident or diagnosis. The information reported includes demographics of the injured/ill worker such as age, sex, years of total mining experience, and years of experience at current mine, as well as information related to the mine location where the incident occurred, days away from work, days of restricted work activity, source of the injury, body part(s) injured, and a narrative description of the incident. The subjects in this study's average age at the time of the incident was 39 years and their average mining experience was 14 years. Their job titles, collapsed from 120 different MSHA database designations, fell into one of the following three categories: laborer; technical; or supervisor.

"Laborer" includes rank-and-file workers, such as general laborers and equipment operators; "technical" refers to mechanics, electricians, and engineers; and "supervisor" includes production foremen, electrical foremen, maintenance foremen, and other supervisory personnel.

Approximately 30% of the subjects in the population were identified in the laborer category; 54% were identified in the technical category; and 14% were identified as supervisors. Subjects had been in the technical job title for an average of 10 years when the reported arc incident occurred.

3.1.2. Narratives

In the written reports MSHA mandates of all "reportable" incidents at every mine in the United States there is a narrative written by someone at the mine describing the incident. The quality of the information varies widely, from highly detailed to sketchy. These three examples show the nature of some of the information recorded for arc flash incidents:

(Incident 1) "Employee was tightening battery terminal on truck when the wrench he was using made contact with metal box. The wrench when shortened made contact with employee ring and he received third degree burn on ring finger."
(Incident 2) "Disconnect flashed when turning off"
(Incident 3) "The ee used ether to clean the contact points instead of the contact cleaner as provided. Subject is a certified electrician. He was wiring the load side of a

400 amp circuit breaker. Evidently, the ground lead came into contact with the A&B phase leads causing an arc and flash when power was applied to the breaker"

In narratives such as these, information relating to behavioral characteristics is clearly limited, so in order to gain any insight into personal conduct of the victims, interpretations and situational judgments had to be made. To this end, a study team consisting of a psychologist, a sociologist, and several mining engineers read the accident reports and discussed conflicting understandings and opinions expressed in the narratives. After a pilot study of 50 narratives each, the team developed an evaluation criteria to apply to the narratives to tease out useful behavior related data. Employing their collective expertise, two principal categories were established, namely O*rganization of Work* and *Activity.*

3.1.3. Criteria

The first principal category, *Organization of Work,* refers to the categorization of incidents based on key elements that contributed to the incident. Three elements were identified by the study team. First, if it was determined that an incident was "beyond the control of the worker," then it was classified as a mechanical/technical failure. If the incident was not a mechanical/technical failure, then the team had to make an expert judgment about whether or not the worker "recognized the hazard." This conclusion was based on the nature of the hazard, the victim's background, and experience as reported in the narrative. Finally, if it was determined that the victim was experienced enough to recognize the hazard, then it became an issue of the worker making a decision to engage in a specific behavior that eventually led to an incident.

The second principal category, *Activity,* refers to the work activity of the victim at the time of the incident — routine maintenance, troubleshooting, repair, or normal job. Because the narrative data is often sketchy, two additional elements were added — "Unknown/Undetermined" and "Other."

Other variables taken from the MSHA accident reports were: amount of time into shift when the incident occurred; body parts injured; total mining experience; and job experience when the arc flash incident occurred.

Data for total mining experience and job experience were collapsed. For these variables, the data were recoded into experience levels of *less than 2 years; 2 but less than 5 years*; *5 but less than 10 years*; and *10 years or greater*. Researchers were also interested in how much time had elapsed into the worker's shift before the incident occurred. "Time at work" data were collapsed into the categories of *less than 2 hours*; *2 but less than 4 hours*; *4 but less than 6 hours*; and *6 hours or more*.

3.2. Phase Two

3.2.1. Interviews

In the second phase of the study, a self-reporting measurement technique was used to collect information from persons who were either *victims of* or *witnesses to* an electric arc flash event. This was a natural extension of Phase One, as researchers sought additional, more in-depth behavioral data. It was decided that personal interviews of such individuals could provide valuable insight into both individual and organizational behaviors. The MSHA National Mining Academy helped identify subjects in the mining industry and the International Brotherhood of Electrical workers identified workers in general industry. Because the focus of the investigation was on the human and organizational behavior aspects of arc flash incidents it was not important what industry the subject's represented.

Participants were asked to give a detailed account of the event, their work activities at the time of the incident, their job experience and qualifications, and a retrospective evaluation of their arc flash incident. For the latter, subjects were asked to assess, from their perspective, causes and possible prevention. Additionally, participants were asked to complete a six-item survey about the safety climate in the workplace where the arcing event occurred. Researchers adapted questions from the general NIOSH Generic Job Stress Questionnaire Safety Climate Survey for this study (NIOSH, Division of Behavioral and Biomedical Sciences; DeJoy et al., 2004; Zohar, 1980).

The focus of each interview was on the person's description of various behavioral aspects of the event, not on its technical features. Thirty of the interviews were conducted in person; two were completed by phone.

3.2.2. Subjects

The sample consisted of 32 persons; 27 were arc flash victims and 5 were witnesses to an arcing event. Eighteen of the subjects were working in the mining industry when the incident occurred and 14 were employed in general industry. Fifteen of the 18 mining industry workers were employed at underground mines, and 3 were working at surface operations. The final sample size was determined by the "saturation" of responses. That is, when researchers hear the same information from subjects again and again, saturation in data gathering has been achieved.

The number of subjects interviewed at that point would represent the complete sample (Glaser & Strauss, 1967). The present study reached saturation after interviewing 32 persons.

Assistance in locating subjects was provided by State and Federal (MSHA) mine district personnel, independent mine trainers, and the International Brotherhood of Electrical Workers (IBEW). Subject participation was voluntary and anonymous.

3.2.3. Focused Interview Guide

The data collection instrument used in this study was an interview guide (Appendix A). Four separate interview guides were developed. Each focused on a different group of subjects. The four groups and the number of persons in each group included the following: victim of an arc incident working in the mining industry (13); witness to an arc incident working in the mining industry (5); victim of an arc incident working in general industry (13); and witness to an arc incident working in general industry (1).

The interview guide consisted of both open-ended and closed-ended (yes or no) questions. An "other" category was added to allow subjects to respond in any way they liked. In effect, this allowed researchers to further explore the respondents' thoughts. The questions covered demographics of participants, incident details, victim/witness perceptions about the incident, and organizational safety culture. Two researchers and the interviewee met in a quiet setting at the person's workplace. Notes were taken by the researchers during the interviews, and all information was coordinated, coded, and incorporated into a Microsoft Excel file for reduction and evaluation.

Participants were asked not to identify themselves or their company in writing by name. Thus, the information was totally anonymous and subjects were assured of confidentiality. The amount of time extended per interview ranged from approximately one hour to well over two hours. Net interview time depended upon the respondent's motivation and interest in contributing to the discussion.

To assess the safety of the work culture at the time of the incident, questions from the NIOSH generic safety climate survey were adapted and completed by each subject. Responses to the six questions (Appendix A) were asked using a rating scale of 1 to 4. One is associated with a less safe or more negative safety culture, and 4 represents a safer or more positive safety culture.

3.2.4. Limitations of the study

This is a descriptive study utilizing a causal–comparative method and, as such, can only be used to explore causal relationships, not confirm them. The sample is a non-probability one called a haphazard sample of convenience. Since the selection of collaborators was indiscriminate and arbitrary, it is obviously not a representative sample, and results cannot be generalized. Nevertheless, participants did enable researchers to achieve their objective, as they supplied first-hand information of actual arcing incidents and, thus, provided documented insight from which particular aspects of their behavior before, during, and after the arc event could be identified. This study, as in all self-report studies, is limited by the subject's recall. In addition, the limitations of the MSHA narrative data must be noted as discussed earlier.

4. Results

4.1. Phase One

Analyses were performed using the evaluative criteria described in the Method of Study section. In the first element of the *Organization of Work* category, Mechanical/Technical, a total of 284 of the 836 incidents (~34%) resulted from electrical component failure. It was determined that these cases had no organizational or behavioral component, so they were eliminated, and the remaining 552 cases were used for the analysis.

Under the second element, Hazard Recognition, in the category *Organization of Work*, subjects did not recognize the hazard in 45% (251 of 552) of the cases. In 55% of the cases, workers did recognize the hazard. For example, if a qualified electrician worked "live" when it was not necessary, it was concluded that, based on his qualifications, training, and experience level, he *should* have recognized the hazard in performing the task and turned the power off before starting.

The third element, Judgment and Decision-making, combined recognition of the hazard with judgment and decision-making. For example, if a qualified electrician was injured because the power was not turned off, and it was not absolutely necessary to work "live," then researchers determined that the subject made a choice to work "live." In this element, subjects recognized the hazard *and* made a choice to engage in a specific behavior that led to injury in nearly 55% of the cases (301 of 552).

Looking at all 836 cases with regard to the job title categories of *laborer, technical,* and *supervisor,* it was found that laborers who had been in their occupation less than two years incurred a larger proportion of incidents than technical (more qualified) workers who had been in their jobs the same amount of time. However, in looking at both classifications of workers — laborers and technical — after 10 or more years of experience, a larger proportion of incidents were incurred by the technical workers. In other words, the more experienced technical personnel were victims of a larger proportion of the arc flash incidents than the laborers in the study population. Moreover, the large majority of technical workers in this group were qualified electricians.

With respect to the job title categories at the time of the incident, most workers injured by arc burns were "electricians" or "mechanic/repairmen" (technical). They comprised 54% of all cases. For supervisors, the proportion of arc flash incidents resembled those for technical personnel, with the largest proportion of incidents occurring to supervisors with 10 or more years in their job. With respect to work activities for all occupations of workers, 74% of arc burn incidents occurred to those doing maintenance/repair/troubleshooting activities.

Electricians incurred 84% of their injuries while performing "electrical maintenance/repair" services, while mechanics sustained more than 52% of their injuries performing "electrical maintenance/repair" activities, usually identified as troubleshooting. Troubleshooting was the single most frequent work activity in which the victims were engaged.

Approximately 20% of the accidents happened less than two hours into the shift, almost 25% occurred in the second two hours, and approximately 23% happened between four and six hours into the shift. It was found that the largest proportion of injuries, approximately 32%, occurred 6 hours or more into the worker's shift.

Finally, for electricians in the study population, 45% of the arc flash burn injuries occurred to the hand or fingers; 28% to the eyes; and 16% were to the wrist, arm, and forearm. In a large majority of the incidents, injuries occurred to multiple parts of the victim's body.

4.2. Phase Two

In the focused interview guide discussed in the Method of Study section, six open-ended questions and a six-item safety climate survey were posed to the subjects.

The first question related to certain demographics of the victims/witnesses and the specific details of their arc flash incidents. The majority of participants (~72%) were classified as electricians. The number of years working in this job title ranged from 3 to 37 years, and 87% of the sample had more than 6.5 years of experience in their job title when they had the arc flash incident. The age of subjects at the time of the incident ranged from 24 to 55 years old. The average was 37 years old with 16 years electrical experience. Nine of 10 victims were qualified to perform the electrical tasks in which they were involved when the arc incident occurred. In 87.5% (28 of 32) of the incidents, the subjects had received formal electrical training and were certified electricians. Further, almost three-fourths of the victims had five or more years of electrical experience.

Nearly 60% of voltages in which an arcing incident occurred were 480 volts AC. The working voltages ranged from 440 AC to 4160 AC and from 128 DC to 560 DC. Eight of 32 participants were involved in DC arcing incidents. Most of these occurred with trolley systems in underground mines. Twenty-three of the 32 subjects (78%) were performing maintenance/repair or troubleshooting when the arc flash incident occurred.

Subjects were asked if they were injured and which body parts were affected. Twenty-eight of 32 said they were injured. They reported arc burns to the hand and fingers (41%); eyes (34%); and wrist, arm, and forearm (38%). More than 90% of the incidents resulted in injury to multiple parts of the body.

Next, subjects were asked to describe, in as much detail as possible, the arc flash incident in which they were involved. Their responses provided ample amounts of first-hand data from which some behavioral information could be gleaned. Here is an example of one incident description:

A qualified electrical maintenance foreman with 4 years of electrical experience was doing troubleshooting work on the lighting circuit on a continuous miner. He began his investigation by pulling fuses at the 480 V to 110 V transformer feeding the circuit. He was looking for continuity in the lighting circuit (110 V AC) side of the transformer. His volt-ohmmeter was set on resistance and everything checked out. He then began to check for power at the 480 VAC fuse holder. In a hurry to get the continuous miner running as soon as possible, he accidentally left his volt-ohmmeter set on resistance. As he began to check for power on the high voltage side of the transformer, the meter exploded and a phase to phase arcing–fault occurred at the fuse holder. He received 3rd degree burns on approximately one-half of his right hand. In his own words: "I was lucky I didn't get hurt a lot worse because I wasn't wearing safety glasses or gloves. I was careless and worked on something that was energized and didn't need to be because I was in a hurry." He indicated the incident absolutely could have been prevented. He also said from that point on, he made it a practice to work on any electrical problem only with proper PPE.

Additional behavior information was provided in several follow-up questions about their perceptions of the incident they just described. The first question was "Do you believe this incident could have been prevented? If yes, how could it have been prevented?" Nearly 94% of the participants (30 of 32) stated that the incident could have been prevented. The two leading explanations for how it could have been prevented were *appropriate use of PPE* — 47% (15 of 32) and *lockout/tagout* / *shouldn't have worked live* — 41% (13 of 32).

The next question asked the subjects to indicate what they feel is important in preventing arc flash incidents. Responses included *don't work in such a hurry; be more careful; don't take shortcuts; think the job through*; *better job preparation*; *follow accepted work procedures*; and *don't be complacent*. Other replies to this question were *better maintenance of electrical equipment* and *better communication* and *become aware of other workers' actions*.

When asked why arc flash incidents happen *and* what these incidents have in common, the leading group of responses included the following:

- *hurrying to get the job done* - (16 of 32)
  includes *don't want to inconvenience customer* and *production pressure*
- *inadequate electrical training* - (10 of 32)
  includes *work not done by "qualified*" *electrician*
- *complacency* - (10 of 32)
  includes *lack of attention to task*
- *carelessness* - (6 of 32)
- *working "live"*- (6 of 32)
  includes *failing to lockout/tagout*

Other noteworthy responses to the questions of why arc flash incidents happen and what they have in common included *not following accepted procedures*; *poor maintenance of equipment*; *not using PPE*; *insufficient planning to see job through*; *worker out of position in work area*; *poor judgment*; *using improper testing equipment*; and *lack of communication*.

Subjects were then asked what could be done to make it less likely that workers would be exposed to arc flashes. The leading responses were *wear PPE* — (10 of 32); *turn power off* — (9 of 32); *follow rules and policy procedures* — (8 of 32); and *modify design of electrical equipment* — (6 of 32). Other suggestions included *training in awareness of arc dangers*; *don't take chances*; *think the job through*; and *eliminate bad habits*. Several of these suggestions are noted in the following account:

A qualified electrical general inside laborer with 6 years of electrical experience was running a 15-ton GE motor that was hauling empty supply cars on a Saturday maintenance shift. The pole on his motor jumped the 300 VDC line and wedged between the belt hanger and top of an overcast. He got off the motor on the tight side of the entry and grabbed the base of the "harp" pole with his bare hands. The pole arced between the trolley and the trolley hanger and injured him with flash burns to his eyes and the taste of copper in his mouth. He also got shocked as he became a grounded part of the circuit and was thrown against the ribs. In his own words: "I was in a hurry and I didn't think the job through. I had picked up a bad habit learned from older miners." He said the incident absolutely could have been prevented if he had put on his gloves and not looked at the pole. He also said he was going too fast and that is what caused the pole to jump in the first place.

The last part of the interview guide related to organizational behavior (i.e., the safety climate where persons worked when they experienced an arc flash event). Subjects rated each of six questions (refer to Appendix A, Part B) on a scale of 1 (Strongly Disagree) to 4 (Strongly Agree), with 24 points representing the maximum score. Safety climate responses were grouped as follows: 6 to 15 — poor; 16 to 20 — average; and 21 to 24 — good. Results showed that ~27% of the subjects (8 of 30) reported a poor safety climate; ~46% (14 of 30) reported an average safety climate; and ~27% (8 of 30) said they had a good safety climate.

5. Summary and Discussion

The main objective in this study was to learn of the individual and organizational behavioral factors associated with non-contact arc flash incidents. This was accomplished by investigating various aspects of past incidents, as detailed in official MSHA accident reports, and by conducting personal interviews with victims and witnesses to arc flash events. Information was obtained in two phases: (a) by reviewing 836 mining industry electric arc burn accident reports, and (b) by interviewing 32 persons from mining and general industry who had been victims in arc flash incidents.

The subjects in Phase One represent the population of victims of arc flash incidents in the mining industry over an 11-year period; therefore, their demographic data are statistically reliable. However, as noted earlier in the discussion of the narratives, behavioral data were subject to interpretation. In contrast, subjects in the second phase of the study did not come from a statistically representative random sample. As a result, neither the demographic nor behavioral data collected and reported in this phase can be used to characterize the population of workers who have incurred an arc flash injury. In addition, the incidents subjects reported in some cases happened 15 years previously, while other incidents happened in the past few years. Thus recall bias must be taken into account. Regardless of these limitations, information is reported that appears to be meaningful to the extent that it should be given consideration in designing interventions for preventing or reducing the occurrence and severity of arc flash injuries.

It was observed in both phases of the study that most victims in these arc flash incidents, regardless of the industry in which they worked, were experienced electrical persons who had more than 10 years on the job at the time of the incident. This is meaningful because it opposes the historical expectation that more job experience equals fewer accidents and injuries. The subjects in Phase One averaged approximately 9 years of job experience; the victims in Phase Two averaged 16 years of electrical experience. The large majority of victims in Phase One and Phase Two had also received formal electrical training and were certified electricians.

The subject of electrician training and certification came up in dialogue with several of the interviewees. An issue seldom considered by organizations in hiring electricians is the need to evaluate their electrical qualifications and specific experience. The first question usually asked concerns the qualifications and certifications of the electrician. This query is normally completed by the human resources department. The second question concerns the individual's experience. This usually is not investigated in depth, as there is an expectation that an individual certified as an electrician can do anything electrical. An interviewee shared an experience with the researchers wherein his company had hired an electrician. When a problem arose with the battery-operated power center, the electrician realized that he had worked at mines with electrical current and had no idea how to work on this battery. He was qualified, but he did not have experience in this area of electrical work and consequently was injured. Checking performance on specific tasks is the manner in which proficiency is determined.

The most common job classifications of arc flash victims at the time they were injured were electricians and mechanic/repairman. "The most common work activity of nearly three-fourths of the subjects was electrical maintenance/repair or troubleshooting." There is no established curriculum for electricians in repair and troubleshooting. Companies may provide workers troubleshooting on the company's specific equipment, and when a new piece of equipment is purchased, the manufacturer usually trains the workers. In Phase One, it was found that approximately one-third of the arc flash incidents in these work activities occurred after more than six hours into the shift. This "time-into-shift" data suggests that workers may have been careless, fatigued, or hurrying to get the job done. These explanations are among the several reasons given by Phase Two subjects for why arc flash incidents happen.

The data suggests that one of the more important conclusions in this study is that many workers knew of the potential consequences of their actions, yet made a decision to engage in risky behaviors that led to arc flash incidents. Using the argument that victims had, on average, significant electrical experience and job experience, it can be conjectured that they indeed recognized the hazards of the task in which they were working when the arc flash incident occurred but made conscious judgments/decisions to engage in a risky behavior that led to the event. For example, an experienced electrician should know when to turn the power off while performing a specific task or when to use the correct tool.

Thus, since workers with more experience were getting hurt at higher rates, it is suggested that they were either not recognizing the hazard (unlikely) or making a judgment/decision (more likely) to engage in a risky behavior leading to the accident. Experienced electrical workers who have the knowledge and know the correct procedures are making judgments/decisions to engage in a behavior that eventually leads to an arc flash incident. Why? Some reasons given by Phase Two subjects included: time pressures (that is, hurrying to get the job done because they don't want to inconvenience the customer), production pressures, insufficient planning to see the job through, and taking shortcuts. For these reasons, workers tend to work "live," not use PPE, and, in general, not follow accepted work practices.

In Phase One incidents, it was determined that in a substantial number of instances the worker recognized the hazard and made a decision to proceed with behavior that led to the incident. In practically every interview in Phase Two, the issue of making a judgment/decision to complete an assignment by taking a short-cut was mentioned even though the worker knew it was wrong to do so. Comments like these were made: *I was careless and did not think through the job…I didn't follow procedure…I let the boss's time pressure affect my judgment on what was safe…I made a decision not to turn the power off…I have been working in this area for many years and have made choices to take shortcuts because I "knew" what I was doing…I figured I could do this quick without taking the time to put on the gloves (or glasses or other protective gear)…I had done this a thousand times and nothing had ever happened….*

Several questions relating to the prevention of arc flash incidents were asked of the interviewees in Phase Two. The first one asked, in retrospect, was if the incident in which they were involved could have been prevented. Ninety-four percent of the subjects answered "yes." The number one preventative measure suggested was "turn the power off." The data on body parts that were injured in arc flash events are reported in both phases of this study and indicate that the arc flash burns affected multiple parts of the body. This finding suggests that appropriate PPE is important for electricians, regardless of the task they are doing.

Besides the relevance of PPE for preventing arc flash injuries, the subjects also seemed to point to the importance of behavioral issues. Specifically, there was a recurring behavioral theme in responses to follow-up questions relating to what subjects feel is important in preventing arc flash incidents; why these incidents happen; what they have in common; and what could be done to make it less likely that workers would be exposed to an arc flash event. Leading responses to such questions included: *don't work in such a hurry; be more careful and don't take chances; don't take shortcuts; think the job through; don't be complacent; follow accepted work procedures; use PPE; turn power off.*

The safety culture of an organization is generally recognized as an important component for insuring individual worker safety. However, arc flash incidents appeared to occur to subjects in Phase Two irrespective of the organization's outlook on safety. Seventy-three percent of the incidents reported occurred to individuals who worked for organizations that had an *average* or *good* safety culture. It cannot be concluded from this study that safety culture is not important, only that with this small sample it did not seem to play a major part in behavior. Several subjects indicated their companies had an excellent safety culture. They also indicated that even in the best of circumstances the unexpected can happen.

Interestingly, within the more positive safety culture, individual decision-making represented a major part in determining behaviors that led to the flash incident. Thus, it may be suggested that this particular group of subjects, working in what they judged to be a safety conscious company, took more responsibility for their own actions. The other major pattern in the more positive safety cultures was the pressure for production, generally evidenced as supervisory demands. Thus, the management's positive safety climate was not necessarily reflected in front line supervisors, who must balance the safety needs with production needs.

In the less positive safety cultures, workers reported inconsistency in training and communication. In addition, the pressure of production and supervisor demands was a major factor in the behaviors that led to the incidents.

Deenergizing equipment before performing maintenance and repair is clearly the best protection against the occurrence of an arc flash. For troubleshooting activities, however, power must usually be left on. In this case, electrical safe work practices must be adhered to and workers must be appropriately qualified. Focused and effective training, not just technical but also behavioral, is perhaps the best way to achieve this objective.

6. Recommendations

Based on conclusions from the data, the authors make the following specific suggestions related to training:

1. *Utilize the Safe Job Performance Model* to guide the development of non-contact electrical arc programs to include the hierarchy of engineering controls, administrative

controls, and behavior controls. First, work at engineering the hazard out of the workplace, then, apply administrative controls such as policies and standard operating procedures, and, finally, include behavior interventions, such as attitudes, safety culture, and personal responsibility. Include knowledge and skills necessary for safe performance and integrate judgment and decision-making skills into training curriculum.

2. *Target at-risk populations* including:
   a. *new, inexperienced workers* (those with less than three years on the job). This population is usually targeted with present electrical safety programs in the acquisition of skills and knowledge.
   b. *qualified workers* (certified electricians and mechanics with 10-16 years or more experience). MSHA designated job categories of electrician and mechanic/ repairman
   c. *supervisory personnel*
3. *Method:* Use a *recommended training format for adult learners*. Utilize methods proven successful for adult learners, such as hands-on instruction, experiential classroom learning, on-the-job-training, coaching, and building on the worker's knowledge.
4. *Content* of training for electrical safety programs should focus on technical skills, knowledge, and judgment decision-making skills. Overall, present programs provide very good skills training and electrical knowledge acquisition. The authors suggest that introducing a judgment and decision-making curriculum including awareness and hands-on problem solving situations could impact the frequency of non-contact electrical arc incidents. This content would include a discussion of the reasons *why* qualified electricians choose unsafe behaviors, and it would include findings from this study.

Electrical safety curriculum should raise awareness of activities performed that have been shown to be more dangerous, specifically troubleshooting and repair activities. Present training seems to focus on installation and maintenance. The authors suggest that attention also needs to be paid to the non-routine type of activities found daily on the job, such as troubleshooting and repair. Safer techniques to perform these activities need to be developed. In addition, discussion of increased vigilance six hours into a shift should be included in the curriculum.

Use appropriate *personal protective equipment* (PPE). PPE can reduce injuries to the hand, fingers, eyes, wrist, arm, and forearm. PPE can mitigate the extent and severity of arc flash injury. One individual in the study said, "Always be prepared to 'gear-up.' No matter how smart you are or how well trained, no one can prevent the unexpected from happening, so be prepared."

It is judicious to acknowledge that human behavior does affect the application of engineering and administrative controls and the success of behavioral interventions. Interventions on the worker level should not be discouraged by supervisors or peers. Non-contact arc flash incidents will continue to happen. The authors want to emphasize that, in their analysis the single, most important finding from this study is the key role that judgment and decision-making play in the frequency and severity of injury in these incidents. Raising awareness, through training of worker's on-the-job judgments and decision-making would be an important step toward reducing these serious, debilitating, and sometimes fatal incidents. The authors recommend further study in this area.

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Appendix A

Non-Contact, Electric Arc Burn Injuries

MV Interview Guide / 2004

The purpose of this questionnaire is to collect information from miners who have been the victim of a non-contact, electric arcing incident.

Background

Eight hundred and thirty-six non-contact, electric arc burn incidents were reported to MSHA between 1990 and 2001. These incidents resulted in three fatalities and more than 12,000 lost workdays (LWD). This number of lost workdays accounted for over one-third of all LWDs due to electrical injury in the mining industry during the eleven-year period. A review of narratives for these incidents indicated that the most dangerous types of work activities for causing arc burn injuries are electrical and machine maintenance/repair.

This type of injury has become more common because modern mining practices require higher capacity electrical distribution systems that have heavy, available short circuit currents and energies that can initiate and sustain electrical arcing faults. In an effort to reduce the incidence and severity of arc burn injuries, NIOSH is developing training recommendations for the purpose of improving hazard recognition and judgment/decision making skills of miners for recognizing and avoiding electrical hazards that could result in arcing incidents.

(A) Non-Contact, Electric Arc-Induced Burn Injury Incidents

1. The following questions relate to *you*, the *victim* of a non-contact electric arcing incident. Please answer them as carefully as possible. If you need more writing space, use the back of this sheet.

a. What were you doing (work activity) at the time of the incident? (check one)

Maintenance	______
Installation	______
Repair	______
Troubleshooting	______
Other: ____________	______

b. What was your job title *and* years of experience in that job when the incident occurred?

	Years Experience
Electrician	______
Mechanic / Repairman	______
Laborer	______
Other: ____________	______

c. What voltage were you working with at the time of the incident? (check one)

660 V	______
661–1000 V	______
More than 1000 V	______
Other (specify)	______

d. What was your age at the time of the incident?

e. Were you a qualified electrical person when the incident occurred? Yes No

f. If yes, how did you become qualified?

1. Training (specify):

2. Experience (specify):

g. How many years had you been a qualified electrical person when the incident occurred?

h. Were you injured in the incident? Yes No

i. If yes, which body parts were injured?

j. Describe, in detail, what happened in the incident.

k. Do you believe this incident could have been prevented? Yes No

l. If yes, how could the incident have been prevented?

2. From your experience, which of the following are important in preventing arcing injuries?

a. Improved PPE

What type?

b. Training

What kind?

c. Changes in work procedures or practices

Describe the changes?

d. Other factors

3. Why do you believe non-contact, electric arcing accidents happen?

4. What do most non-contact, electric arcing incidents have in common?

5. What could be done to make it less likely that miners would be exposed to electric arcing?

6. Considering the different tasks in a Mine Electrician's job, which ones are most likely to cause the electrician to become exposed to arcing?

Please indicate how much you agree or disagree with each of the following statements about safety behavior in the mining company where you worked when you had the arcing incident.

Use this scale for each statement and circle your choice.

Strongly Disagree	Disagree	Agree	Strongly Agree
1	2	3	4

1. New employees were told up front that they were expected to follow good safety practices.	1	2	3	4
2. There were no significant compromises or shortcuts taken by management when worker safety was at stake.	1	2	3	4
3. Employees and management acted together to insure the safest possible working conditions.	1	2	3	4
4. Employees were warned when they did not follow good safety practices.	1	2	3	4
5. The safety of workers was a big priority with management where I worked.	1	2	3	4
6. I felt free to report safety violations to my supervisor or	1	2	3	4